Statement of

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"Space Situational Awareness: Guiding the Transition to a Civil Capability"

Chairman Beyer, Ranking Member Babin, and distinguished members of the Subcommittee, thank you for inviting me to join this discussion. I am on the staff of The Aerospace Corporation, a non-profit Federally-funded Research and Development Center whose purpose is to provide advice to the Government on all aspects of the nation's space enterprise. The full thirty-three years of my career have been spent in the Space Situational Awareness (SSA) domain, which has included the design and development of space sensors and command and control systems; basic research on SSA data exploitation algorithms; large-scale simulation of SSA systems; and in the last decade of my career, as a subject matter expert for NASA on the orbital safety problem. I also serve on the graduate faculty of Baylor University and advise dissertations in the Department of Statistical Sciences. It is a great pleasure to give testimony today on the subject that has constituted my life's work.

Introduction

The space population has grown tremendously in the last decade, and recent FCC and ITU filings for large satellite constellations make clear that the rate of growth is likely to remain high. At the same time, the relevant space debris population from existing debris fields decaying into more populated orbital regions and from fresh debris production, such as from the recent Russian ASAT test, is also growing. In combination, this makes the operational orbital safety mission—a set of activities to prevent active satellites from colliding with space debris and with each other—increasingly difficult. The USG's support to the civil and commercial orbital safety enterprise is presently performed by the DOD, which has always been an awkward mission for a military organization. The growing demands in this area are likely to consume more and more resources, could distract the DOD from their principal mission to protect and defend against military threats (rather than natural and unintentional hazards), and increase the disconnect yet further between the needed and actual R&D and architecture investments needed to meet the operational demands of the present and evolving space activities and ensure long term sustainability of the space environment. This collection of difficulties explains the present impetus to transfer the USG's support to the civil and commercial orbital safety enterprise to a civilian governmental agency, in which there can be both undistracted mission focus and advocacy for the needed short- and long-term investments.

Transitioning this capability and responsibility poses considerable challenges. Accessing the DoD precision space catalogue data from a civil location for execution of the civil and commercial orbital safety mission software is more complex than is generally supposed – especially if one wishes at the same time to update the computer architecture, create a twenty-first-century data exchange mechanism with space operators, and adopt a modest set of proposed algorithmic and methodological improvements from recent academic research that could notably enhance mission performance. Additionally, in an area that previously had been the purview of government, there is now a robust and rapidly growing space situation awareness (SSA) commercial enterprise, offering everything from raw space tracking data to full space catalogues to advanced orbital safety calculations and services; one would certainly wish to attempt to take advantage of the innovative offerings of this burgeoning industrial sector in a reconstituted orbital safety capability. These two considerations conspire to make a seemingly simple transfer of capability and responsibility instead a challenging proposal.

To address the question of how this transition should be executed, it is necessary to examine the different parts of the orbital safety enterprise in order to understand the particular issues and opportunities presented by each. It is best to begin with a discussion of the concept of the space catalogue, as this is the foundational element of nearly all space applications. Next, the operational orbital safety mission will be decomposed into its three component parts, and the challenges and favored transition approaches for each of these will be discussed. After this, known gaps in the present approach and algorithm set will be identified, with paths to resolution suggested. While throughout this whole treatment the question of commercial data and services will be considered as it applies to each part, an extended discussion of the role of commercial data, especially commercial measurement and satellite position data, in the overall enterprise will be given a collective evaluation. Finally, the question of how to evaluate and examine flight safety R&D products, whether offered by academia or industry, that have the propensity to improve the civil agency's flight safety mission execution, will be considered

The Precision Space Catalogue

If the goal of operational orbital safety is to protect active satellites from collisions with space debris and with each other, the enabling first step is to know what objects are in Earth orbit, where they are, and where they are expected to be some number of days into the future. The name given to this collection of information used for accurate astrodynamics calculations is the precision space catalogue.[1] It consists of both the position and velocity of every known space object (the position and velocity of a satellite are called the satellite "state"), a statement of the uncertainty with which each satellite state is known (called a "covariance"), and the collection of the orbital models that will allow the satellite state to be predicted forward into the future so that the satellite's location at some future time can be determined. There are two ways objects can be added to and maintained as part of a space catalogue: they can be discovered and tracked by satellite tracking sensors and have orbits built for them (the only method available for derelict spacecraft, rocket bodies, and space debris); or the owners/operators (O/Os) of active satellites, who know the present and predicted state information for their spacecraft, can submit this information to be added to a space catalogue. The particulars and issues associated with each of these methods are discussed separately below.

The "non-cooperative" space catalogue maintenance method, which involves space sensors discovering/tracking objects and a central processing facility to receive tracking information and build orbits, is both difficult and expensive. Space sensors, especially for tracking objects in low-Earth orbit (called "LEO" satellites, which have orbital altitudes less than ~2000 km and constitute the bulk of both operational satellites and space debris), usually require radar technology, which is complicated and expensive both to build and operate; and a large number of sensors is needed to obtain satellite tracking over all different parts of a satellite orbit. The generation of satellite orbits from tracking data is difficult and requires both specialized software and subject matter experts to massage the orbit parameters manually for sparsely-tracked orbits, difficult-to-maintain orbits, or situations with corrupted or misfiled satellite tracking data. This complicated, cumbersome, and expensive set of activities is already being performed by the DoD for military purposes, so it is unsurprising that the civil agency charged with taking on this mission for civil and commercial satellites is seeking to obtain the DOD space catalogue, which is complete down to objects approximately 10 cm in size in LEO, for use as the foundational datastore for the orbital safety mission.

There are also several industrial actors who operate their own space tracking sensor networks and maintain their own space catalogues, often with claims of including objects smaller than the publicly available DOD catalogue and thus being more complete. For at least some orbital regimes, these claims are plausible; so the question naturally arises whether a civil orbital safety capability should purchase access to such expanded catalogues and by doing so thus be able to provide more comprehensive orbital safety calculations and recommendations. It is certainly true that working from a more comprehensive space catalogue will produce a more comprehensive result, but there are additional considerations that make the decision more complicated.

It is often presumed that the use of a more comprehensive space catalogue will help to reduce the production of space debris, for it will allow the identification and prevention of satellite collisions that would have produced large amounts of such debris. While more data are

[1] It is important to distinguish between the "high-precision" space catalogue, which uses precision numeric orbit modeling, is required for meaningful orbital safety calculations, and is in bulk shared with only a few agencies within the USG; and the "low-precision" space catalogue, which uses analytic modeling, produces a fast but imprecise solution, and is posted publicly on the Space Force's www.space-track.org website for unrestricted public download.

always beneficial, the improvement is not linear and, for the current LEO situation, expected to be muted. While the dynamics of satellite collision debris production are complicated, analysis shows that the creation of notably large amounts of debris usually requires the collision of two objects larger than about 10 cm in dimension. Because the current DoD catalogue is considered reasonably complete to this object size, an enhanced satellite catalogue with more complete holdings at smaller sizes, while perhaps beneficial for other reasons, is unlikely to make a notable difference in reducing the production of space debris.

Debris production aside, orbital safety calculations based on a more complete catalogue would help to identify and avoid collisions that could end satellite missions. This is a high priority for human space flight; but beyond human-space-flight applications, it may make sense to distinguish between orbital safety improvements that protect the collective good of preserving a space environment free of debris pollution and those that provide primarily individual goods for individual O/Os. The latter may be more appropriately addressed by an advanced service that can be purchased by O/Os should they desire it. This is a policy issue to be considered by the orbital safety civil agency in setting up the parameters of their service.

To complete the discussion of the population of the space catalogue, it remains to describe the alternative mechanism for establishing state and uncertainty information on an active spacecraft, namely receiving this information directly from the satellite O/O. Such a submission generally takes the form of an ephemeris, which is a file containing a series of satellite states at regular time intervals (one-minute intervals are typically used for LEO) usually spanning several days into the future. This method of state representation is substantially superior, one might even say essential, for the orbital safety mission because an O/O ephemeris can both be much less uncertain than one derived from external measurements and, perhaps more importantly, can contain and represent a satellite's planned future maneuvers, which allows the satellite's planned trajectory changes to be considered when identifying close approaches between this satellite and other space objects. The DOD presently accepts O/O ephemerides to use in its orbital safety calculations (although it does not take the next step of using these data to update its official catalogue), but it does not perform any quality checking or validation on these submissions. Some O/O ephemerides, in both their state predictions and uncertainty assessments, are quite good; others are poor. There are presently no established standards for accuracy and precision of such submissions—and there hardly could be, as presently such submissions are voluntary—nor is there any funded entity to evaluate O/O ephemerides to certify their validity. Because O/O ephemerides truly are necessary for credible orbital safety calculations for on-orbit spacecraft that can intentionally change their trajectories, the orbital safety civil agency will quite likely need to work with the FAA and FCC to establish the regular furnishing of this information as a requirement for obtaining a launch or spectrum allocation license; and they will need to establish a capability to evaluate O/O ephemerides to ensure that they meet needed accuracy and precision requirements to enable credible orbital safety calculations. Because both government and private actors will be relying on these O/O data and calculations for critical safety decisions, this type of certification activity includes elements of an inherently governmental function and should expect to be performed either internal to the government or by an independent entity that is free of any financial interest in the outcome.

The Orbital Safety Process

The process of determining whether protected satellite assets are likely to collide with any other space objects, and guiding mitigating actions to avoid any such collisions, comprises three distinct parts:

I. Conjunction Screenings predict the orbits of a protected satellite and all other satellites in the space catalogue several days forward into the future and look for close approaches between them. For any satellites that are expected to come within a particular proximity threshold (which varies by orbit type) to the protected satellite, the states and uncertainties for both objects at the time of closest approach, as well as some other amplifying information, are used to generate a conjunction data message (CDM), which is then dispatched to the protected satellite's O/O.

Receiving a CDM might be considered analogous to the "check engine" light coming on in one's vehicle. It does not mean that an enduring problem exists—indeed, the light (if the author's experience is any guide) often goes off after a few minutes and then stays off; but if it stays on, then it would be wise to take the car to a mechanic to examine the situation more closely. Similarly, receipt of a CDM, especially several days before the time of closest approach, does not indicate an immanent collision; but if CDMs continue to arrive and the predicted proximity between the two satellites remains disturbingly small, then it is prudent to proceed to the next step of the process to see if a durable problem actually exists.

II. Risk Assessment is the careful examination of the CDM history to determine if the conjunction actually represents a high-risk situation. A specialized set of calculations are performed, based on the data in the CDM, to determine both the likelihood of an actual collision, generally expressed as a probability of collision; and the consequence of collision, generally expressed as the number of trackable pieces of debris that would be generated were the conjunction to result in a collision. Examining these results in the overall context of the event establishes whether the conjunction manifests enough of a safety risk that a mitigation action should be pursued.

The risk assessment step is analogous to taking one's vehicle to the mechanic after the "check engine" light has persisted for some time. The mechanic examines the situation and determines if there is a problem that merits actual repair or whether the warning light is just calling attention to something that is not particularly serious. The courses of action here are not always cut-and-dried: a driver who is risk-adverse and truly wants to avoid being stranded by a breakdown may choose to proceed with repairs that are only marginally necessary; a driver who is risk-tolerant may decline such repairs as not required at the present time. The same sorts of discussions occur between orbital safety risk assessment specialists and satellite O/Os regarding the appropriateness of mitigation actions.

III. Mitigation Planning is the identification of a trajectory change to the protected satellite, in response to a worrisome risk assessment from Part II, that will both avoid the risky conjunction and not introduce any new risky conjunctions. Typically this involves generating trade-spaces that allow O/Os to see what different satellite maneuvers executed at different times might achieve in terms of reducing overall collision likelihood, allowing them to choose a maneuver that resolves the current orbital safety problem and aligns with other satellite mission objectives.

This step is analogous to a mechanic's actually making repairs on a vehicle. Through discussions, the owner and mechanic decide precisely which of several different repair actions are to be pursued, and the repairs are then accomplished. Similarly, the risk assessment specialist and the O/O decide on the actual mitigation action, which the O/O then realizes as a formal maneuver plan.

<u>Orbital Safety Process Transition</u>

There are a number of different ways that the transition of the USG's support of the civil and commercial orbital safety mission from the DoD to a civilian agency can be accomplished. The particular approach described below, which treats the transition of the three different parts of the process separately, appears to the author to present the lowest transition risk, to enable operational responsibility by the civil agency most rapidly, and to further the competing goals of the overall transition in a balanced way.

In discussing Part I (numeration from previous section), which is the conjunction screening process that results in production of CDMs, it is important to note that this represents the entirety of what the DoD provides to civil and commercial entities for orbital safety—the DoD does not provide risk assessment or mitigation planning assistance (Parts II and III). So in discussing the "transition" of the orbital safety mission from DoD to a civil agency, it is really only Part I that is a candidate for transition; if it is desired that the civil agency provide the Parts II and III services, then such a capability will need to be implemented *ab initio*. But in the presence of the DoD space catalogue, the execution of conjunction screenings and the production of CDMs is a straightforward process, driven by a single DoD algorithm set that has sustained full numerical validation and well over a decade of operational exercise.

The first step in an orbital safety transition from DoD to a civil agency is thus to transfer the Part I capabilities from DoD and implement them as presently formulated (with appropriate minor modifications for changes in computer architecture) and an improved portal for data exchanges with satellite O/Os and other organizations. An unclassified version of the DoD Space Catalogue, along with certain additional supporting files, can be exported from the DoD operational database, run through a further declassification procedure, and transferred to the civil agency at regular intervals each day. The DoD algorithm set for orbital safety screenings can then be run on the civil agency system and used to generate CDMs, which can be distributed through a modern distribution portal.

This approach confers a number of advantages. It is known that the DoD data export procedure described above can be accomplished because it is presently used in exactly this same form to declassify and transfer the DoD space catalogue to another civil agency multiple times per day. The DoD algorithm is highly parallelized, so improved computational performance can be achieved easily by adding additional computational capability. A first step of simply preserving existing capability but with faster turn-around times and an improved user interface is a prudent confidence-building measure with O/Os. Finally, an initial goal that is not overly technically challenging is a good setting for working through the attendant bureaucratic encumbrances and difficulties that transitions such as this invariably engender.

Both the research community and private industry presently offer orbital safety screening algorithms that would appear to be equally accurate to the DoD algorithm yet more computationally efficient. The civil agency would be encouraged to investigate such algorithms and potentially pursue a future upgrade, but a change of the basic algorithm for orbital safety screenings is not recommended until after the transition is complete. Once an R&D evaluation environment is stood up (to be discussed later) and the DoD screening algorithm transitioned and thus available to use as a benchmark for both screening accuracy and performance, then the civil agency will be in a good position to evaluate potential screening algorithmic improvements. But taking on a major numerical validation effort to certify a new algorithm to serve as the core of the orbital safety mission in the midst of a transition activity is seen as unwise.

As remarked earlier, the activities that represent Parts II and III of the orbital safety process (risk assessment and mitigation planning) are not presently performed by the DoD for civil and commercial O/Os. A variety of different sources of solutions are pursued instead: some O/Os limp along with almost no regularized risk assessment and mitigation planning services at all; some have small in-house services for these functions; some contract with third-party commercial providers; and some organizations have enterprise-level solutions for this for all of their missions, examples of which include NASA and the EUSST (European Union Space Surveillance and Tracking Support).

Because of the highly federated set of possibilities for Parts II and III, and because there is already a significant set of commercial vendors presently performing these functions, the situation seems a natural fit for the “advanced services” concept,” for which O/Os contract for such services with a vendor of their choice. A role for private industry would fit especially well here because a substantial component of risk assessment and mitigation planning assistance could be described as “bedside manner”—helping to walk the O/O through the risk assessment / mitigation process; interpreting data and calculations that can often be both daunting to understand and initially alarming in their implications; and providing a structured decision framework, especially for events that may develop quickly and thus require rapid decision-making. Additionally, an advanced service could duplicate a basic service but render it with more flexibility and lower latency. For example, if the basic conjunction screening service offered by the civil agency preserved the DoD approach of performing collision screenings (Part I) only once every eight hours, an O/O who wished on-demand screening results might be able to obtain this with a purchased advanced service, presuming that the service provider was in some way able to arrange for access to the civil agency’s space catalogue.

Since the DoD does not perform the Part II and III activities, the orbital safety civil agency will need to decide what posture they wish to take towards these activities. They could take a completely *laissez-faire* attitude much as the DoD has done, they could facilitate such industry-provided services by allowing vendors to offer these services through the civil agency's user interface portal and (with O/O permission) enabling such vendors to obtain appropriate CDM and other data directly, or they could also provide some of the basic risk assessment calculations as part of the CDM as an enhancement to the DoD basic ("free of user fees") service. Both budget constraints and a desire to avoid competing with private industry would counsel against the government's providing too many of the Part II and III activities as part of the basic service; but there are a few small calculations that could be performed to improve the orbital safety decision-making of budget satellite operators without undermining demand for higher-end services, especially since the complexity of the orbital safety topic will ensure an abiding demand for the "bedside attendant" aspect of services for those with expensive assets at stake.

Needed Improvement: Orbital Safety for Autonomously-Controlled Satellites

A major advance in satellite flight dynamics technology has recently been realized in the area of autonomous satellite control—the ability for satellites to maintain and operate in a specified orbit entirely through on-board algorithms, without any human or computer intervention from satellite ground control. Such autonomous capabilities can even include orbital safety. The world's largest satellite constellation, SpaceX's two-thousand-spacecraft Starlink fleet, operates with this paradigm: at each ground contact, each satellite downlinks its intended future trajectory, this trajectory is submitted to the DoD for conjunction screening, the CDMs generated from the screening are returned to SpaceX and uploaded to the satellite, and the satellite makes its own risk assessment and mitigation decisions, without any involvement from ground control. This orbital safety approach is workable, albeit with some restrictions, as part of the current broader orbital safety ecosystem, but with one substantial exception: the advent of two autonomously-controlled constellations operating in proximity to each other. In such a case, which has not yet arisen commercially but surely is not far away, when two satellites from different autonomously-controlled constellations come into a high-risk conjunction with each other, how is the conjunction resolved? Neither satellite knows what the other satellite's intentions are, and there is no expedited communications path by which to exchange such information; so there is a very real possibility that the two satellites could both elect to maneuver and both choose maneuvers that in the end cause them to collide. Such an outcome may seem far-fetched, but it is not: the well-known Iridium-COSMOS satellite collision event of 2009, which produced over 2000 pieces of catalogued debris, took place because, due to the primitive nature of orbital safety operations at that time, the Iridium satellite unwittingly maneuvered into the COSMOS oncoming trajectory. A number of possible solutions have been proposed within the discipline; and the intersection of policy, supporting technical analysis, and interagency cooperation needed develop a durable solution that will be both transparent and recognizably fair, and integrate this solution into the FAA/FCC licensing process, will of course present a number of challenges. The civil agency acquiring the orbital safety mission must recognize that the technical solution for calculating and distributing orbital safety data is really the ten-minute overture to the five-hour Wagnerian opera of policy questions and satellite norms-of-behavior development required in order to ensure safe operation of an enterprise that is changing and developing at a dizzying rate.

Commercial SSA Data

As remarked previously, there is now a robust commercial industry, with multiple independent providers, of commercial SSA data, offering data products that include sensor tracking data on satellites, solved-for orbits, and predicted ephemerides. There are also non-commercial sources of such data upon which the civil agency could potentially make arrangements to draw, such as data collected by the SSA capabilities of the European Union or those of other emerging SSA actors such as Australia. Because it is in general correct to state that increasing the amount of quality data available to the orbital safety enterprise will improve the orbital safety calculations, there is a natural expectation that the civil agency should make broad use of these additional data sources in order to realize such improvements. In the main, this expectation is informed and reasonable; but there are a number of important caveats and limitations that should be considered.

First, for objects that already receive substantial tracking, such as large objects in LEO, and which do not maneuver frequently, additional tracking from non-DoD sources is unlikely to make a meaningful improvement in the quality of orbital safety products. These products are influenced most strongly by decreases in the uncertainty associated with satellite state estimates, and for well-tracked objects the state uncertainty decreases roughly with the square root of the number of measurements used in orbit determination; this means that for objects that already receive a large number of such measurements, the marginal improvement of adding additional data is very small. Efforts to obtain additional SSA data should therefore focus on orbits and objects that presently experience a paucity of tracking data, as this is where meaningful improvements from such additional data will be observed.

Second, there is a mismatch between the kinds of SSA data that would be most easily integrated with the DoD data to produce composite orbital safety calculations and what the commercial SSA sector is likely to offer for sale. There is broad agreement among astrodynamicists that the best technical solution to merging DoD and commercial SSA data is to obtain the sensor tracking data from both DoD and commercial sources and combine them in a single orbit determination process, performed at a single operations center. Unfortunately, this superior technical solution is also the most challenging from an economic perspective. Selling individual measurements to the USG, especially if the measurements can then be redistributed throughout the USG for multiple uses by different agencies and also inform orbital safety products that are then distributed free of charge by the orbital safety civil agency, cuts against the business models for the commercial SSA industry. There also has historically been a reluctance by the DoD to share or redistribute their sensor measurement data, which could potentially reveal vulnerabilities to adversaries.

If it is not possible to obtain and combine sensor measurement data, a plausible alternative is to purchase predicted satellite ephemerides from commercial providers and "fuse" these with an ephemeris generated from the DoD satellite catalogue in order to produce a single, presumably superior, ephemeris that can be used to represent a satellite's predicted future positions. There is developed astrodynamics theory outlining how such a fusion can be legitimately accomplished, although such constructs do not (yet) appear to have been tested on any large scale. But what is known is that for this fusion approach to work, the uncertainty estimates contained in the purchased ephemerides must be highly reliable. Realistic state uncertainty estimation is one of the most difficult problems in orbit determination and prediction, and it is presently only rarely performed well. If an ephemeris-fusion approach to data combination is to be pursued, it will be necessary to empanel a group of astrodynamics subject matter experts to evaluate the fidelity of purchased ephemerides, both in-depth initially and continuously in a monitoring capacity, to ensure that that accuracy and precision of these products continue to meet standards necessary to produce meaningful fusion-based products. In alignment with previous comments about space catalogue validation, this activity is an inherently governmental function and must be performed by individuals or groups with no financial interest in the outcome.

Finally, it is claimed in some circles that a lack of adequate SSA data is the main problem facing the orbital safety mission presently and the principal reason that orbital safety "requirements" are not being met. While it is true that more SSA data is likely to be helpful to the enterprise, the calculations needed for collision risk assessment, especially when combined with the proper logical decision framework for determining the necessity of mitigation actions, are designed to be operable at a variety of different data abundance and quality levels. There are no particular levels of SSA data supply at which the calculations suddenly become relevant or actionable. Different data levels will change the counts and ratio of serious event false alarms and missed detections, but the desirable levels for these parameters is a matter of policy and cost-benefit analysis. Because in general more data translates to better orbital safety calculations, determining when sufficient SSA data are being secured will remain a prudential judgment.

Orbital Safety Research and Development

In the last decade, orbital safety has been an active area of both academic and industrial astrodynamics research. The scope of such research has been broad, with all areas of the discipline touched: improved screening algorithms; improved risk assessment paradigms, parameters, and calculations; improved decision support constructs, especially in anticipation of much larger satellite populations; and proposed satellite norms of behavior. An orbital safety agency should certainly wish to avail itself of all of these potential improvements; but at the same time it is extremely difficult to evaluate the rectitude of the claims made in research papers and studies, especially since in many cases the proposed constructs are tested only against simulated data.

One approach to facilitating the evaluation of the results of such research is to build into the civil agency's orbital safety system an experimental subdivision to allow the hosting of proposed algorithms or tools. Within this subdivision, experimental software could be run against a historical archive of SSA data (which could be simply the operational SSA data but with an enforced posting delay of weeks or months in order to nullify any current operational relevance) and compared to baseline results, as well as the calculations from other experimental tools. Such an arrangement could substantially facilitate the evaluation of proposed replacements for the core algorithms that are part of the free orbital safety service (thus allowing the free service to evolve in accuracy and efficiency), and it could also serve as a venue for advanced services to establish and demonstrate their capabilities to potential O/O customers. Because the space environment is changing so rapidly and the orbital safety discipline is so dynamic, it is recommended that the civil agency orbital safety system contain from its very beginning this accommodation for testing and demonstration of new capabilities.

Conclusion

There is indeed a myriad of issues associated with the transition of the USG's support of the civil and commercial orbital safety mission from the DoD to a civil agency; and for this reason, a step-based approach that deliberately avoids overreach in each such phase is seen as the most promising. The first such step is the transition of the catalogue screening and CDM generation mission from the DoD to a civil agency, using a declassified version of the DoD space catalogue and a rehosted version of this single DoD algorithm, with small modifications to place it in a modern computer architecture with a similarly modern communications interface. Once this duplication of the current DoD capability is in place, accommodation for advanced services to provide conjunction risk assessment and mitigation action planning assistance can be made, probably through the civil agency's automated communications interface and perhaps with expedited access to certain catalogue and O/O CDM data. Once this aspect of the architecture is established and working, the question of commercial data use, which will have been a subject of study in parallel with the architecture efforts described above, can be addressed in full, with appropriate data purchases and validation activities taking place contemporaneously. The study efforts will have identified which orbital regions and objects will benefit most substantially from commercial data augmentation and will have resolved the question of whether measurement data should be acquired or whether fusion of ephemerides is a viable and desirable alternative procedure. Alongside all of this activity, the roll-out of the civil agency's orbital safety system will have included an R&D physical/virtual sector, which can be used both for the commercial data study efforts mentioned above and to evaluate the benefits of improved algorithms and approaches for all of the aspects of the orbital safety enterprise. Finally, while all of these transition activities are indeed important, in many respects they are overshadowed by the great need to establish standards, guidelines, and norms of behavior for safe satellite operations. Even with a civil capability successfully producing and distributing safety alerts and data, there is no clear guidance outlining what O/Os should do with such data, how they should negotiate hazardous situations, and what data products they have an obligation to provide in order to contribute to the safety of the entire enterprise. Such a civil agency's supervening task must be to develop, in consultation with all affected parties, reasonable and analytically-grounded standards, guidelines, and norms of behavior for safe satellite operation; and they must integrate these into the launch and spectrum allocation process so that they become a formal part of an O/O's operating instructions. It is only then that space actors will both fully understand their responsibilities and be equally fully motivated to fulfill them.